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RESEARCH MEMORANDUM

AN EXPERIMENTAL INVESTIGATION OF FOUR TRIANGULAR-WING-BODY COMBINATIONS IN SIDESLIP AT MACH NUMBERS 0.6, 0.9, 1.4, AND 1.7

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The lateral-directional-stability derivatives of a body in combination with several triangular wings were determined at subsonic and supersonic speeds. The wings used in the investigation were of aspect ratios 2 and 4 and thickness ratios of 3 and 5 percent. One of the wings of aspect ratio 2 was cambered and twisted. The results indicate that at supersonic speeds the effects of plan form on the lateral-directional-stability derivatives for the plane wings were predicted satisfactorily by linearized theory and that the effects of thickness were small.

INTRODUCTION

One of the difficult problems associated with the design of aircraft with triangular wings is concerned with the lateral-directional flying qualities. The difficulties arise from the large variations of dihedral effect and directional stability with lift coefficient. Major factors influencing these characteristics are the contributions of the wing and the vertical tail. Linear theoretical methods for predicting the effects of wing aspect ratio are available (ref. 1) but largely unsubstantiated.

In order to verify these theoretical methods and investigate their applicability to wing-body combinations, the characteristics of several of the triangular-wing models utilized in the investigation of reference 2 were studied in sideslip. The present report is concerned with these results which show, to a limited extent, the influence of aspect ratio, thickness ratio, and camber and twist on the rolling moments, yawing moments, and side forces due to sideslip.

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SYMBOLS

The symbols and their definitions used in this report are as follows:

C_L lift coefficient, $\frac{\text{lift}}{qS}$[1]

C_Y side-force coefficient, $\frac{\text{side force}}{qS}$

C_l rolling-moment coefficient, $\frac{\text{rolling moment}}{qSb}$

C_n yawing-moment coefficient, $\frac{\text{yawing moment}}{qSb}$

C_{l_β} rate of change of rolling-moment coefficient with angle of sideslip, measured at constant angle of attack, per deg

C_{n_β} rate of change of yawing-moment coefficient with angle of sideslip, measured at constant angle of attack, per deg

C_{Y_β} rate of change of side-force coefficient with angle of sideslip, measured at constant angle of attack, per deg

M Mach number

S wing area, including portion formed by extending leading and trailing edges to plane of symmetry, sq ft

b wing span perpendicular to plane of symmetry, ft

c local wing chord, ft

$\bar{c}$ mean aerodynamic chord, $\frac{\int_0^{b/2} c^2 dy}{\int_0^{b/2} c\, dy}$, ft

l length of body, in.

q dynamic pressure, lb/sq ft

r radius of body, in.

r_o maximum body radius, in.

t maximum section thickness, ft

x distance from nose point along body axis, in.

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[1] All forces and moments are given for the axes as shown in figure 1.

y distance perpendicular to plane of symmetry, in.

α angle of attack, deg

β angle of sideslip, deg

APPARATUS AND TESTS

The investigation was conducted in the Ames 6- by 6-foot wind tunnel, a continuous-operation pressure tunnel capable of testing from a Mach number of about 0.6 to 0.9 and from 1.2 to 1.9. (See ref. 3 for further information.) In this wind tunnel, the models are sting supported with the plane of motion of the system horizontal, and perpendicular to the viewing windows. The angle of attack or sideslip, depending on whether the wing plane of the model is vertical or horizontal, is therefore determined from a calibration of the support-system setting together with corrections to account for the deflection of the support due to aerodynamic loading. During the present investigation, the models were mounted with the wing plane horizontal so that the angle of sideslip could be continuously varied. The angle of attack was essentially constant during each run and was obtained by using a bent sting; a cathetometer was used to measure the angle of attack.

Depending on the size of the model, either of two similar four-component strain-gage balances, one 4 inches and the other 2-1/2 inches in diameter, was used to measure the aerodynamic forces and moments on the models. To obtain the three force and three moment components required in the present investigation, it was necessary to repeat each run with the balance rolled 90°.

Four models, one having a plane triangular wing of aspect ratio 4 and the others having triangular wings of aspect ratio 2, were tested in this investigation. All wings had the NACA 000X thickness distribution. Two of the three triangular wings of aspect ratio 2 were planar and differed only in section thickness, being 3 and 5 percent thick. The third wing, also 3 percent thick, was twisted and cambered to produce a nearly elliptical spanwise loading at a lift coefficient of 0.25 and a Mach number of 1.53. Plan and front views of the plane wings of aspect ratios 2 and 4 are presented in figure 2 and the geometric characteristics of all models are listed in table I.

All the wings were machined from solid steel and hand-finished to produce a surface finish such that the root mean square of the deviations from the mean surface was approximately 20 microinches. The body consisted of a steel spar surfaced with aluminum to form continuous contours and was hand-finished to the same roughness specifications.

All the wing-body combinations in the present program were investigated at a Mach number of 1.4. In addition, the plane wing and the twisted and cambered wing of corresponding plan form and thickness were tested at Mach numbers of 0.6, 0.9, and 1.7. The wing of aspect ratio 4 was tested at a Reynolds number of 1.9×10^6, and the wings of aspect ratio 2 were tested at two Reynolds numbers, 3.0×10^6 and 7.5×10^6. The angle of sideslip was varied during each run from -6° to 6°. The angle of attack was fixed for each run at angles from -2° to 15°.

REDUCTION OF DATA

The wind-tunnel results have been reduced to standard coefficient form as defined in the list of symbols. All forces and moments are given with respect to the axes as shown in figure 1. The origin of this axis system is at the projection of the quarter-chord point of the wing M.A.C. on the plane of symmetry.

Certain corrections have been applied to the wind-tunnel results to account for known differences between the characteristics of the wind stream in the tunnel and free air. At subsonic speeds the data were corrected for tunnel-wall interference resulting from lift on the model by the methods of reference 4. This correction is given by the expression,

$$\Delta\alpha = 0.932\ C_L$$

The methods of reference 5 were used to estimate the increase in Mach number in the vicinity of the model. This effect amounted to as much as 2-percent increase in Mach number at a Mach number of 0.9. Neither of these corrections was required at supersonic speeds; the model was sufficiently small so that at the lowest supersonic Mach number, the reflection from the tunnel walls of stream disturbances caused by the model did not intersect the model.

Based on the precision of the measuring instruments, the uncertainty of data is estimated to be as follows:

Quantity	Uncertainty
Mach number	0.02
Angle of attack	.05°
Angle of sideslip	.04°
Lift coefficient	.003
Rolling-moment coefficient	.001
Yawing-moment coefficient	.0005
Side-force coefficient	.0005

RESULTS AND DISCUSSION

In the present investigation the effects of aspect ratio, thickness ratio, and camber and twist on the aerodynamic characteristics of wing-body combinations in sideslip were determined. These results showed that in the test range of sideslip angles, -6° to 6°, there were no significant effects of sideslip on the lift and pitching-moment characteristics and only a small increase in drag coefficient. Since the longitudinal characteristics were presented in reference 2, they are not included in this report.

The variations of rolling moment, yawing moment, and side force with sideslip angle were linear throughout the range of sideslip angles of the present investigation. It was therefore possible to define the results in terms of the parameters C_{l_β}, C_{n_β}, and C_{Y_β}. The effects of aspect ratio, thickness ratio, and camber and twist on these parameters are discussed separately below.

Aspect Ratio

The effects of aspect ratio on the effective-dihedral parameter, C_{l_β}, the directional-stability parameter, C_{n_β}, and the parameter, C_{Y_β}, were determined at a supersonic Mach number of 1.4 for triangular wings of aspect ratios 2 and 4 with 5-percent thickness ratio; the results are shown in figure 3. The effective dihedral increased with lift coefficient for the triangular wing of aspect ratio 2 and remained zero for all lift coefficients for the triangular wing of aspect ratio 4. A comparison of these results with those estimated by the theoretical methods of reference 1 (fig. 3) shows good agreement throughout the lift-coefficient range investigated. Since the theory of reference 1 applies to a wing alone and makes no allowance for wing thickness, it would appear from these results that neither the presence of the body nor finite thickness of the wing up to a thickness ratio of 5 percent significantly affects the dihedral characteristics of a triangular wing.

The variation with lift coefficient of the directional-stability parameter, C_{n_β}, also shows good agreement with the results predicted by the method of reference 1. The shift in value at $C_L = 0$ is probably due to body effects not considered in reference 1. The experimental curves are parallel to the theoretical curves for both aspect ratios; thus, the effects of the body upon the variation of C_{n_β} with angle of attack are small.

Side-force characteristics for both the wing-body combinations and the body alone are presented in figure 3. These results show that within

the range of the investigation, effects of aspect ratio and lift coefficient upon C_{Y_β} were small. The results for the combination show a sizable value of C_{Y_β} at zero angle of attack. However, this value is consistent with the value obtained from tests of the body alone (ref. 2).

Thickness Ratio

The effects of thickness ratio on the sideslip characteristics are shown in figure 4 for triangular wings of aspect ratio 2 with 3- and 5-percent thickness ratio. These data show no significant effect of thickness ratio on the parameters C_{l_β} and C_{Y_β} and only a small effect on the parameter C_{n_β}.

Camber and Twist

The effects of camber and twist are shown in figure 5 for a range of Mach numbers of 0.6 to 1.7 for triangular wings of aspect ratio 2 and 3-percent thickness ratio. In this comparison, one of the wings is planar and the other is cambered and twisted to give a nearly elliptic load distribution at zero yaw at a lift coefficient of 0.25 for a Mach number of 1.53. These data show that the influence of camber and twist on the rolling moment due to the sideslip is insignificant at subsonic speeds but becomes of appreciable magnitude at supersonic speeds, and produces a uniform positive increment in the parameter C_{l_β} throughout the lift-coefficient range investigated. The yawing moment due to sideslip is influenced by camber at both subsonic and supersonic speeds. At low lift coefficients, camber and twist improve the unstable directional stability but at high lift coefficients, decrease the directional stability.

The results show that at supersonic speeds the side force for the body in combination with the cambered and twisted wing was greater than that for the body in combination with the plane wing over the range of the lift coefficients investigated. At subsonic speeds, however, the side forces of the two wing-body combinations were similar.

CONCLUSIONS

The results of a limited wind-tunnel investigation of the lateral-directional-stability derivatives of four triangular wings of aspect ratios 2 and 4 tested in combination with bodies of revolution indicate the following:

1. Linear theory accurately predicted the effect of aspect ratio on the effective dihedral of wings having a thickness ratio of 5 percent at a Mach number of 1.4.

2. The effects of thickness ratio on the rolling and yawing moments and side forces due to sideslip at Mach number 1.4 were not significant for triangular wings of 3-percent and 5-percent thickness ratios.

3. For the plane wings in combination with a body, the side force due to sideslip at zero lift was the same as that for the body alone.

4. The influence of camber and twist on the rolling moment due to sideslip of triangular wings of 3-percent thickness ratio was insignificant at subsonic speeds but became of appreciable magnitude at supersonic speeds. Camber and twist improved the unstable directional stability at low lift coefficients but decreased the directional stability at high lift coefficients.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Dec. 22, 1953

REFERENCES

1. Ribner, Herbert S., and Malvestuto, Frank S., Jr.: Stability Derivatives of Triangular Wings at Supersonic Speeds. NACA Rep. 908, 1948. (Formerly NACA TN 1572)

2. Hall, Charles F.: Lift, Drag, and Pitching Moment of Low-Aspect-Ratio Wings at Subsonic and Supersonic Speeds. NACA RM A53A30, 1953.

3. Frick, Charles W., and Olson, Robert N.: Flow Studies in the Asymmetric Adjustable Nozzle of the Ames 6- by 6-Foot Supersonic Wind Tunnel. NACA RM A9E24, 1949.

4. Silverstein, Abe, and White, James A.: Wind-Tunnel Interference with Particular Reference to Off-Center Positions of the Wing and to the Downwash at the Tail. NACA Rep. 547, 1935.

5. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effects of Compressibility. NACA Rep. 995, 1950. (Formerly NACA RM A7B28)

TABLE I.- GEOMETRIC CHARACTERISTICS OF THE MODELS

Characteristics	Model A	Model B	Model C	Model D
Wing aspect ratio	4	2	2	2
Wing thickness distribution (streamwise)	NACA 0005-63	NACA 0005-63	NACA 0003-63	NACA 0003-63
Wing total area, S, sq ft	2.007	4.014	4.014	4.014
Wing mean aerodynamic chord, $\bar{c}$, ft	0.944	1.889	1.889	1.889
Wing dihedral, deg	0	0	0	0
Wing camber and twist	None	None	None	(a)
Wing incidence, deg	0	0	0	0
Distance, wing-chord plane to body axis, ft	0	0	0	0
Body fineness ratio (based on length, l, see fig. 2)	12.5	12.5	12.5	12.5
Body cross-sectional shape	Circular	Circular	Circular	Circular
Maximum body cross-sectional area, sq ft	0.103	0.204	0.204	0.204
Ratio of maximum body cross-sectional area to wing area	0.0509	0.0509	0.0509	0.0509
Ratio of body·base diameter to to sting diameter	1.22	1.37	1.37	1.37

[a]Cambered and twisted to produce an approximately elliptical spanwise loading at Mach number 1.53 and lift coefficient 0.25. (See ref. 2.)

NACA

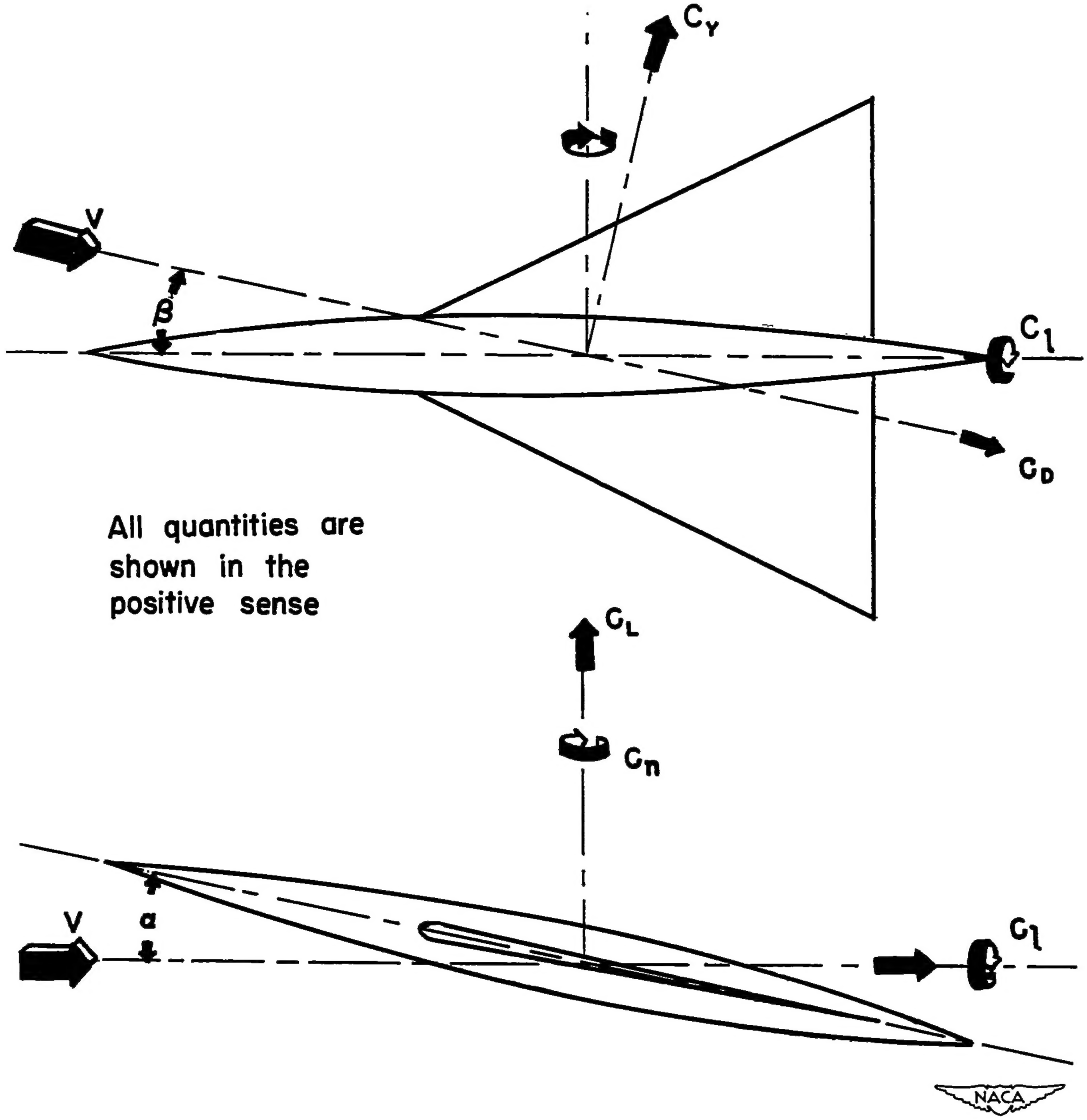
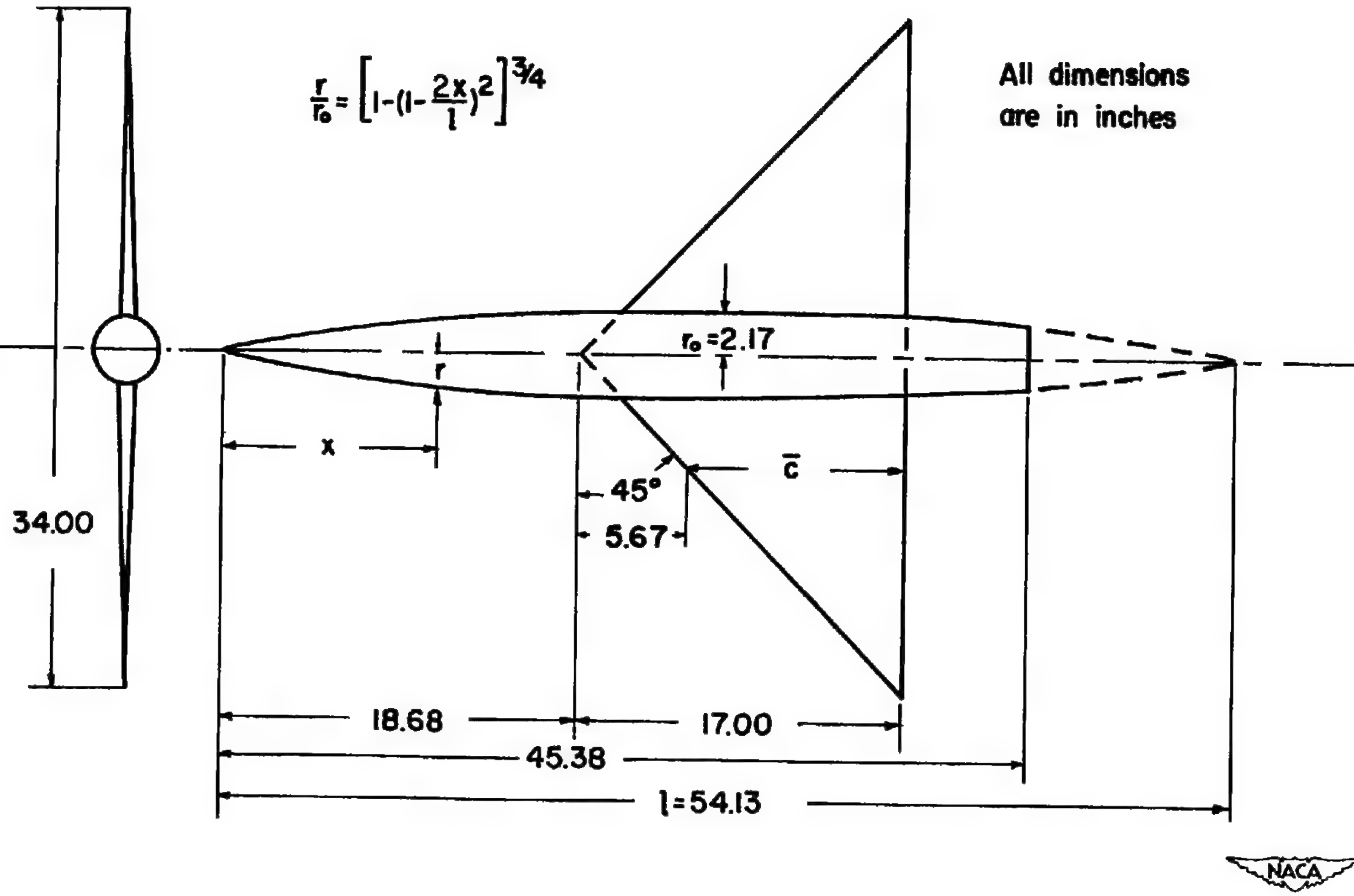
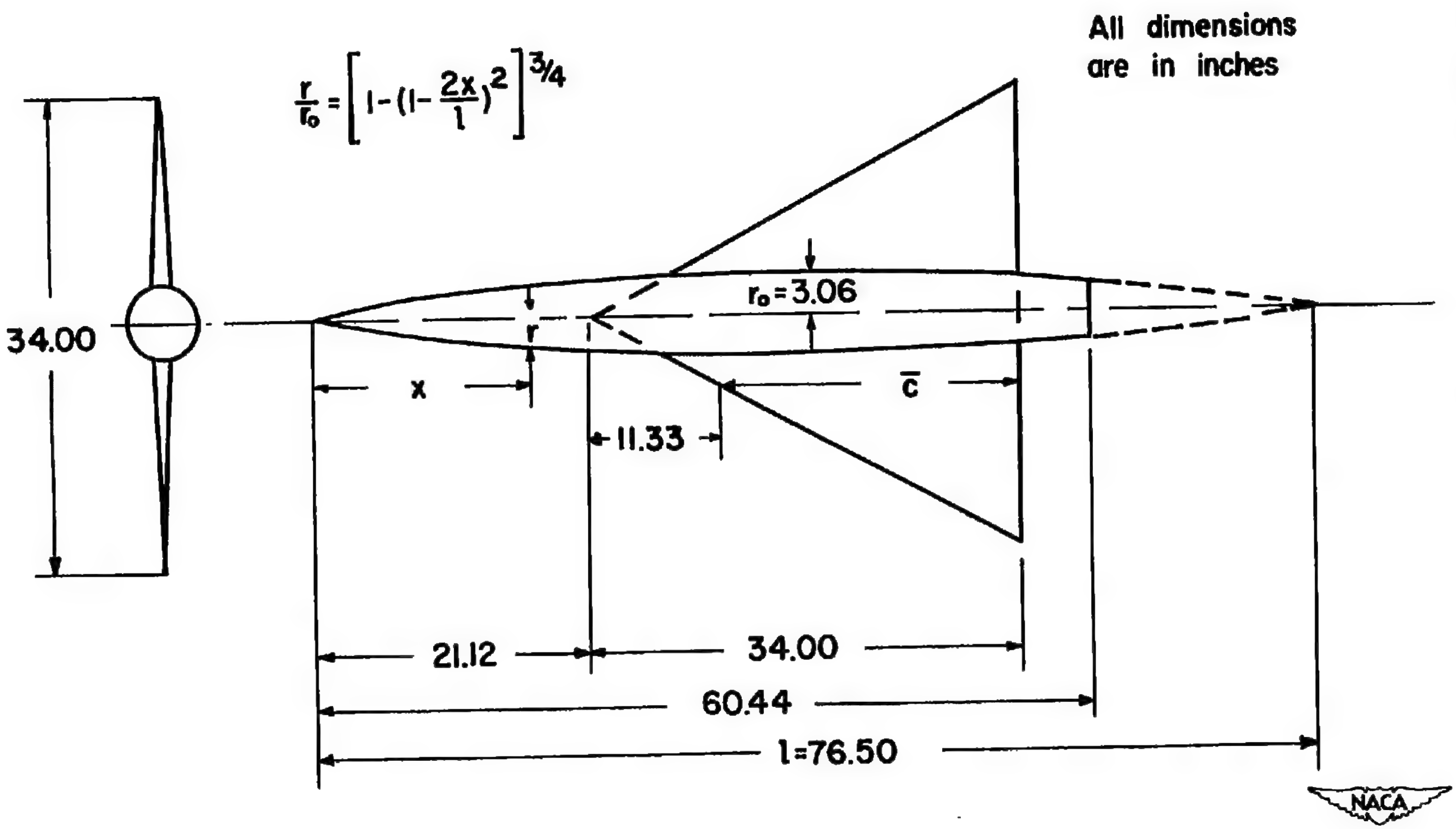


Figure 1.- System of axes used in this report.



(a) Aspect ratio = 4.

Figure 2.- Sketch of test model.



(b) Aspect ratio = 2.

Figure 2.- Concluded.

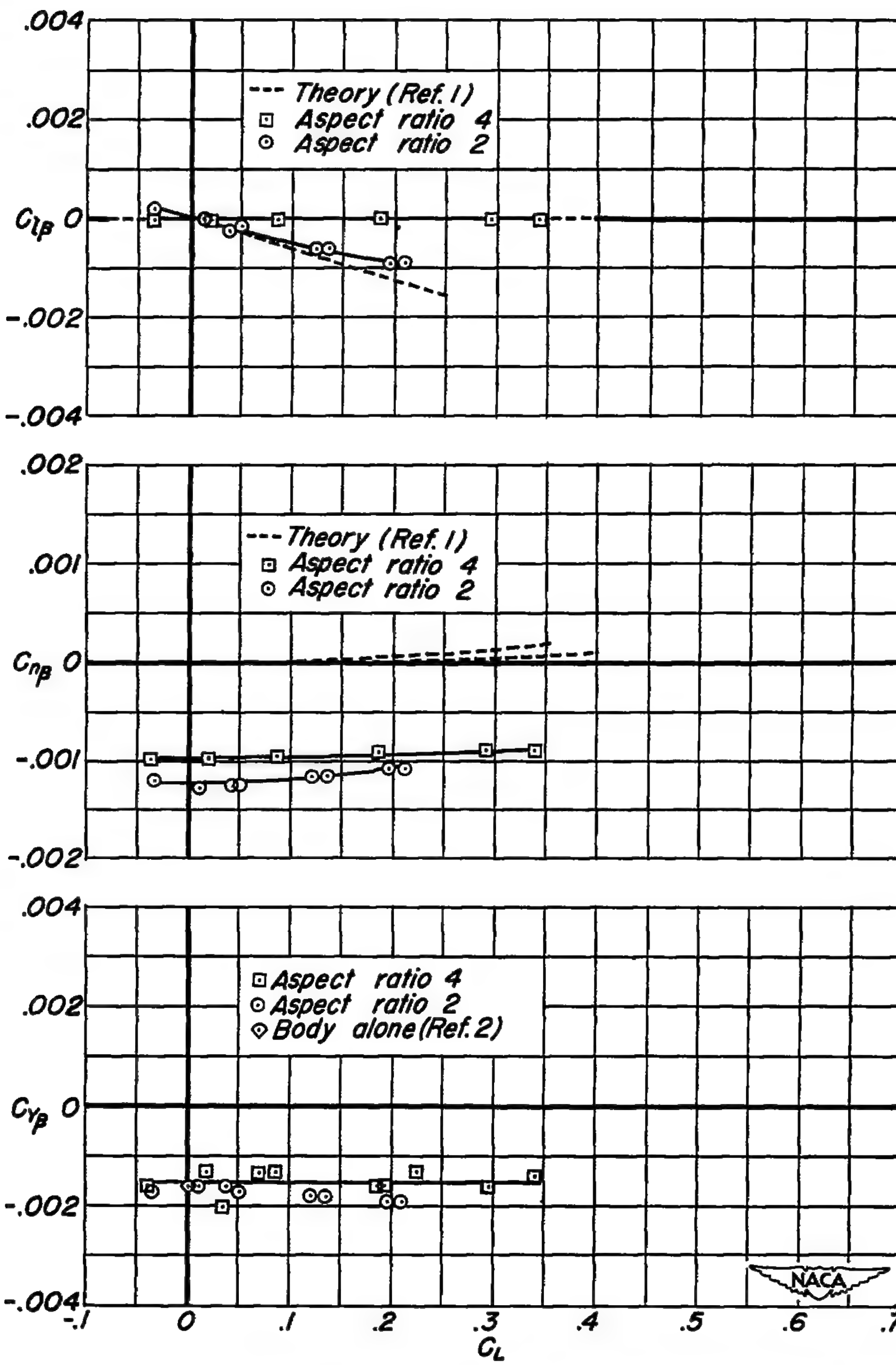


Figure 3.- Effect of aspect ratio on the effective-dihedral parameter, C_{l_β}, the directional-stability parameter, C_{n_β}, and the side-force parameter, C_{Y_β}, for a body in combination with plane triangular wings; $M = 1.4$, $t/c = 0.05$.

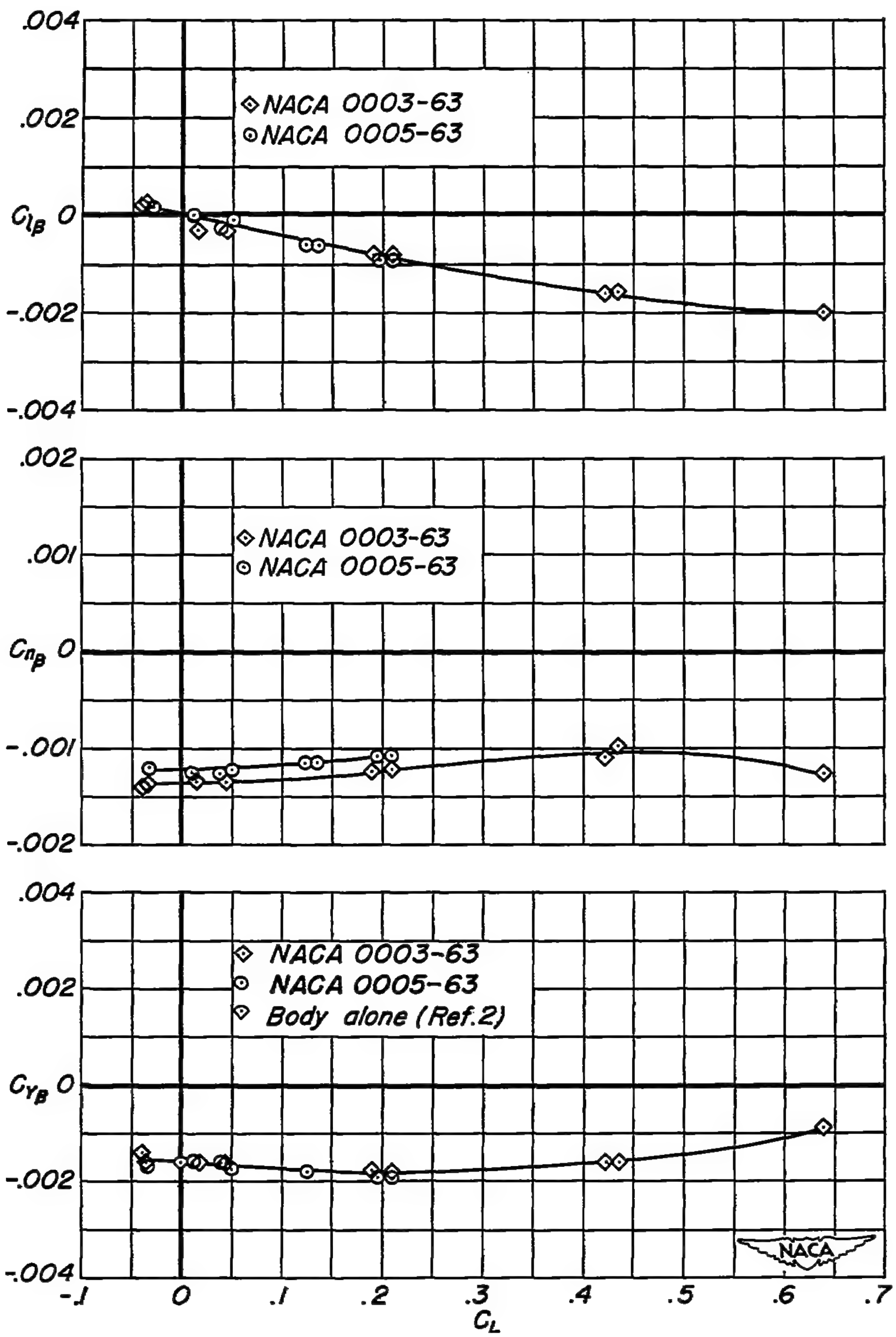
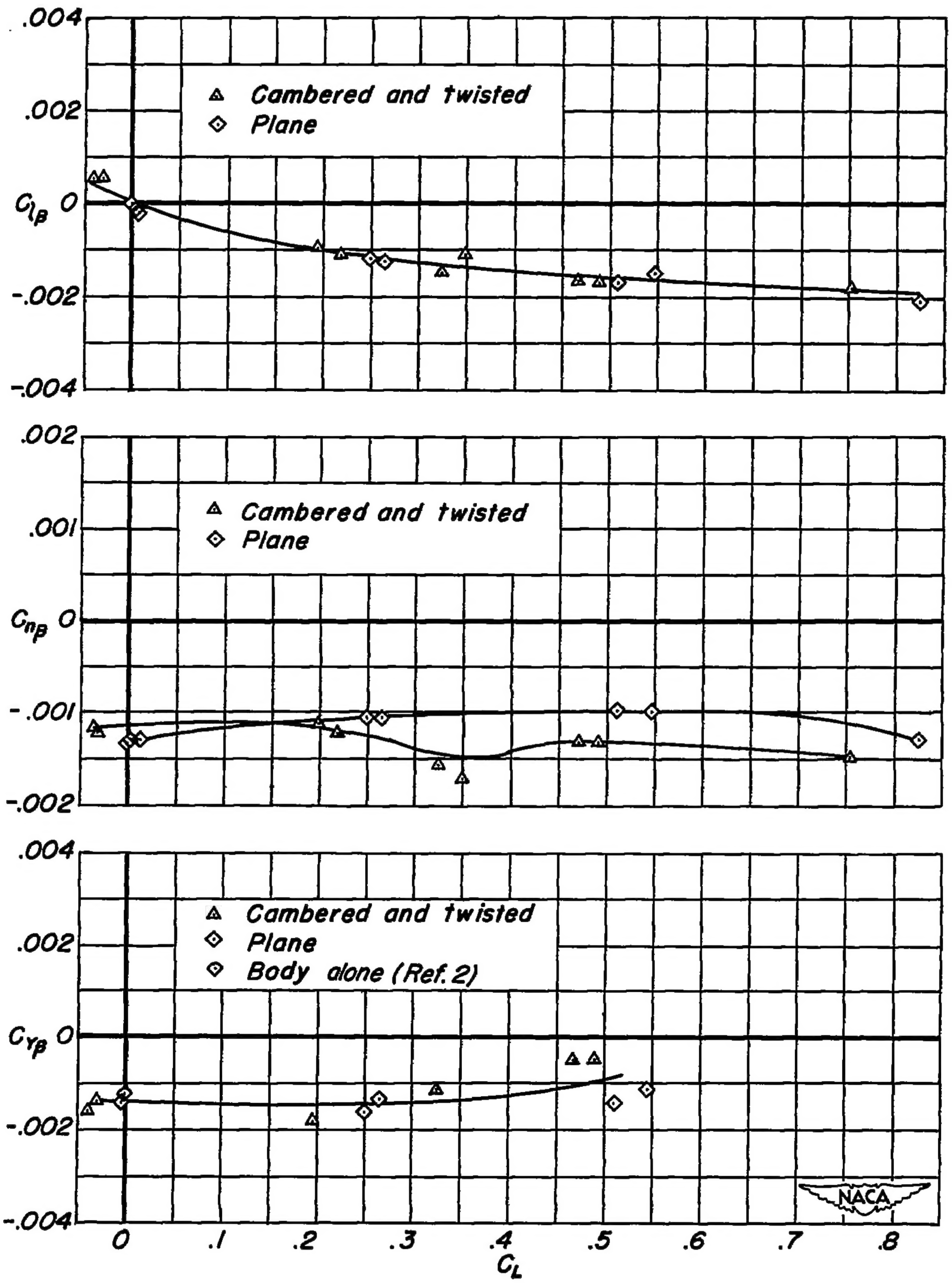


Figure 4.- Effect of thickness on the effective-dihedral parameter, C_{l_β}, the directional-stability parameter, C_{n_β}, and the side-force parameter, C_{Y_β}, for a body in combination with plane triangular wings; aspect ratio = 2; M = 1.4.



(a) M = 0.6

Figure 5.- Effect of camber and twist on the effective-dihedral parameter, C_{l_β}, the directional-stability parameter, C_{n_β}, and the side-force parameter, C_{Y_β}, for a body in combination with triangular wings; aspect ratio = 2, t/c = 0.03.

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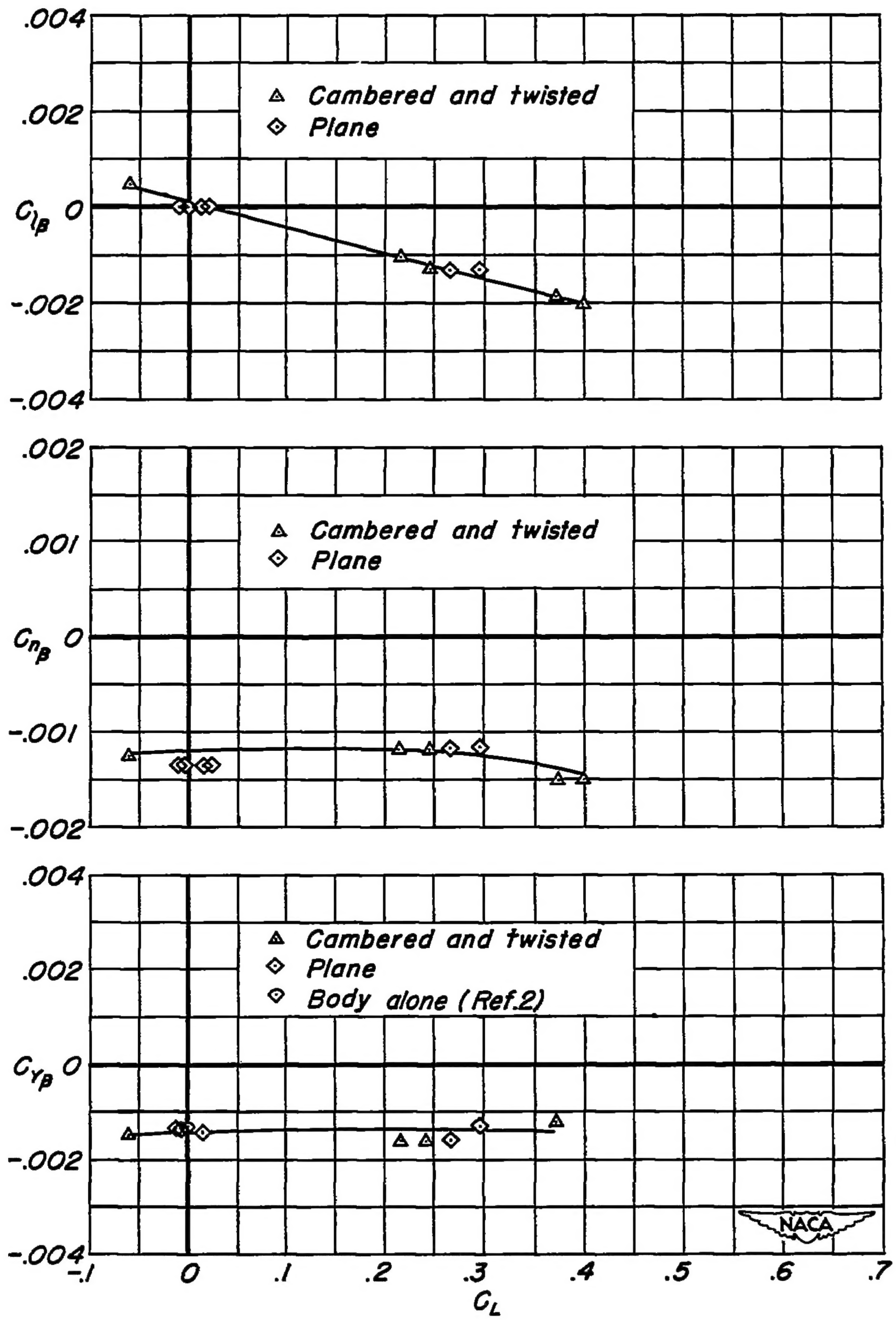
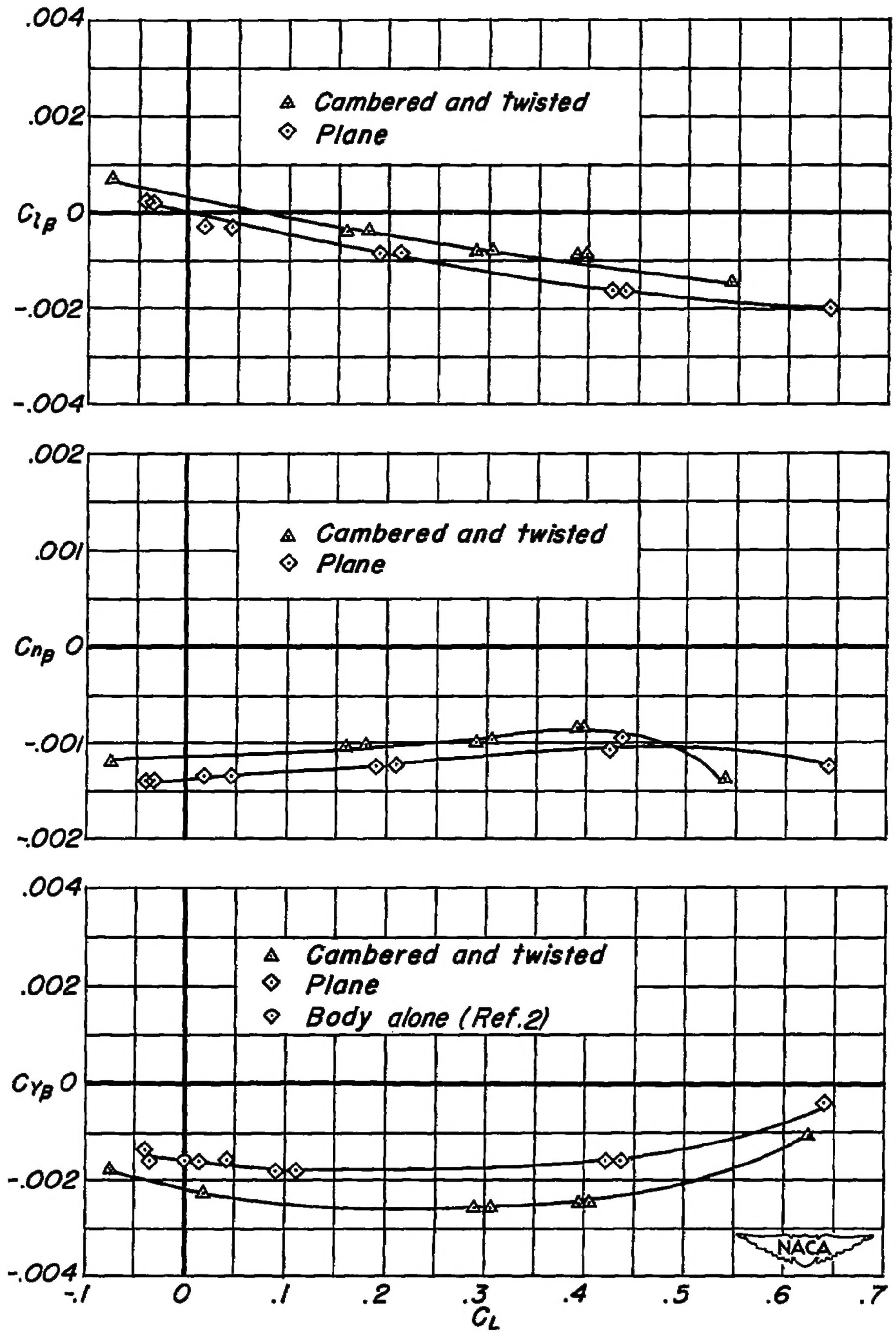


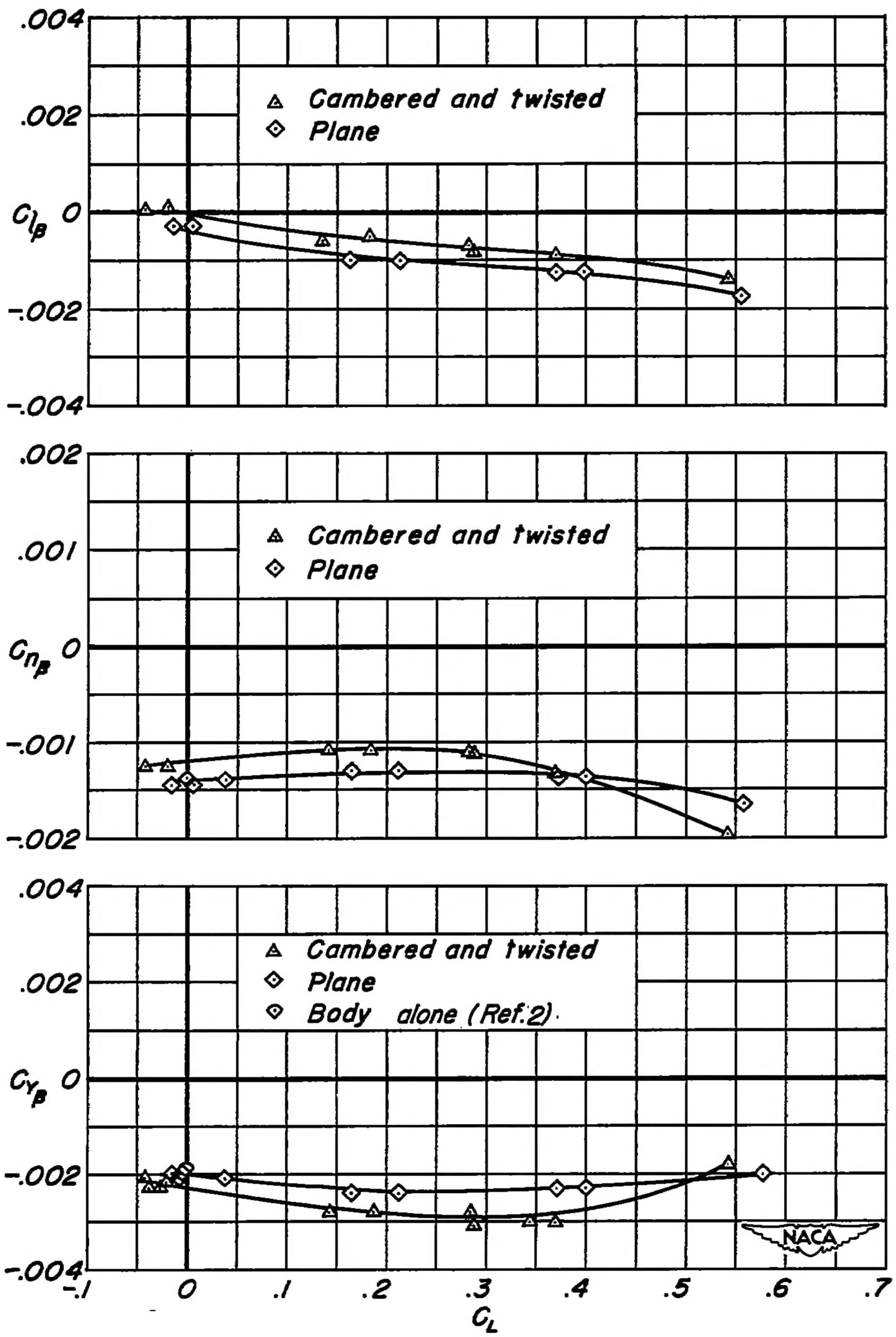
(b) M = 0.9

Figure 5.- Continued.



(c) M = 1.4

Figure 5.- Continued.



(d) M = 1.7

Figure 5.- Concluded.

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